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Plutonium 239 Equivalency Calculations

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Engineering Reference Document

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Contents

1.0 Purpose 3

2.0 Methodology 3

3.0 References 6

Plutonium 239 Equivalency (PuE) Calculation Datasheet 7

Equation 1 PuE (CF, isotope) 3
Equation 2 M,isotope 3
Equation 3 CF Isotope 4
Equation 4 PuE (CF, 30 yr) 4

Table 1 - Isotopic Conversion Factors 4
Table 2 - Typical 30-year-old Weapons Grade 5
Table 3 - 30-year-old Weapons Grade Conversion Factor 5

1.0 Purpose

This document provides the basis for converting actual weapons grade plutonium mass to a plutonium equivalency (PuE) mass of Plutonium 239.

The conversion can be accomplished by performing calculations utilizing either:

1) Isotopic conversions factors ($CF_{isotope}$), or
2) 30-year-old weapons grade conversion factor ($CF_{30\ yr}$)

Both of these methods are provided in this document.

2.0 Methodology

2.1 Isotopic Conversion Factors

Material mass and isotopic data are needed to calculate PuE using the isotopic conversion factors, which will provide the actual PuE value at the time of calculation.

PuE is the summation of the isotopic masses times their associated isotopic conversion factors for plutonium 239. [Equation 1]

Equation 1 PuE (CF, isotope)

$$\mathbf{PuE} = \sum_{\mathbf{0}}^{\mathbf{n}} (\mathbf{M, isotope} \cdot \mathbf{CF, isotope})$$

M, isotope = Isotopic Mass (grams)
CF, isotope = Isotopic Conversion Factor

Equation 2 M,isotope

$$\mathbf{M, isotope} = \mathbf{M, total} \cdot \mathbf{Isotope\ weight}\ \%$$

M, total = Plutonium mass

Isotopic conversion factors are calculated by a normalized equation, relative to Plutonium 239, of specific activity (SA) and cumulated dose inhalation affects based on 50-yr committed effective dose equivalent (CEDE). [Equation 3]

Equation 3 CF Isotope

$$\mathbf{CF_{isotope}} = \left(\frac{\mathbf{SA_{isotope}}}{\mathbf{SA_{Pu239}}}\right) \cdot \left(\frac{\mathbf{CEDE_{isotope}}}{\mathbf{CEDE_{Pu239}}}\right)$$

The isotopic conversion factors for converting weapons grade plutonium to PuE are provided in Table-1.

Table 1 - Isotopic Conversion Factors

Isotope	SA (Ci/g)	CEDE (rem/Ci)	$CF_{isotope}$
Pu238	1.713E+01	4.80E+08	2.63E+02
Pu239	6.133E-02	5.10E+08	1.00E+00
Pu240	2.268E-01	5.10E+08	3.70E+00
Pu241	1.031E+02	1.00E+07	3.30E+01
Pu242	3.931E-03	4.80E+08	6.03E-02
Am241	3.428E+00	5.20E+08	5.70E+01

The unit for specific activity (SA) is curies per gram (Ci/g) and the isotopic SA values come from reference [1].

The cumulated dose inhalation effect values in units of rem/Ci are based on 50-yr committed effective dose equivalent (CEDE). A person irradiated by gamma radiation outside the body will receive a dose only during the period of irradiation. However, following an intake by inhalation, some radionuclides persist in the body and irradiate the various tissues for many years. There are three groups CEDE data representing lengths of time of 0.5 (D) , 50 (W) and 500 (Y) days, which are in reference [2]. The CEDE values in the (W) group demonstrates the highest dose equivalent value; therefore they are used for the calculation.

2.2 30-year-old Weapons Grade Conversion Factor

To calculate PuE using the 30-year-old weapons grade conversion factor, the Pu element mass and knowledge that the age is less than 30 years since separation is needed (no isotopic data required), which will provide a conservative PuE value.

PuE is total elemental mass times 30-year-old weapons grade conversion factor.

[Equation 4]

Equation 4 PuE (CF, 30 yr)

$$\mathbf{PuE} = \left(\sum_{0}^{n} \mathbf{M, isotope}\right) \cdot \mathbf{CF, 30\ yr}$$

CF, 30 yr = 30-year-old weapons grade conversion factor

The conversion factor for 30 year-old weapons grade plutonium ($CF_{30\ yr}$) is calculated using a typical isotopic composition and weight percentage of 30-yr-old weapons grade plutonium values from Table 2 and isotopic conversions factors from Table 1. The Table 2 values are from reference [3].

In using this calculation, the user must know that the material is less than 30 years since separation.

Table 2 - Typical 30-year-old Weapons Grade

30-year-old Weapons Grade Plutonium	
Isotope	**Weight %**
Pu238	0.03
Pu239	93.26
Pu240	5.98
Pu241	0.14
Pu242	0.04
Am241	0.45

$CF_{30\ yr}$ = **1.535** as calculated in Table 3.

Table 3 - 30-year-old Weapons Grade Conversion Factor

Isotope	A. Weight %	B. $CF_{isotope}$	A*B
Pu238	0.03	2.63E+02	0.079
Pu239	93.26	1.00E+00	0.933
Pu240	5.98	3.70E+00	0.221
Pu241	0.14	3.30E+01	0.046
Pu242	0.04	6.03E-02	0.000
Am241	0.45	5.70E+01	0.257
		Total	**1.535**

For a plutonium isotopic mixture that is predominantly elemental Plutonium, the plutonium isotopic mix is qualitatively similar to the hazards and would behave the same as 30-yr-old composition of weapons grade plutonium. The absorption rate, airborne release fraction (ARF) and airborne respirable fraction (RF) of ingrowth material will follow that of the host material. Since Am241 results from the decay of Pu241, Am241 will be in the plutonium matrix and exhibit the same release properties as plutonium, the ARF and RF for Plutonium are used for Americium.

3.0 References

1. LA-12846-MS, Specific Activities and DOE-STD-1027-92 Hazard Category 2 Thresholds LANL Fact Sheet, Los Alamos National Laboratory, November 1994.

2. DOE/EH – 0071, Internal Dose Conversion Factors for Calculation of Dose to the Public, US Department of Energy, July 1988.

3. Facility Safety Plan - Building 332, Lawrence Livermore National Laboratory, July 2009.

Plutonium 239 Equivalency (PuE) Calculation Datasheet

Datasheet to calculate the PuE, grams based on weapons grade plutonium material mass and isotopics. Follow instructions below.

Instructions:

Column A: Enter isotopic weight % for each isotope from the material isotopic datasheet

Column B: Enter the total plutonium mass of the material

Column C: Calculate the isotopic mass by multiplying columns A and B

Column D: Isotopic conversion factors are given.

Column E: Calculate isotopic PuE by multiplying columns C and D-

PuE, total: Calculate total PuE, grams by summing column E

	A	B	C = A * B (Equation 2)	D	E = C * D (Equation1)
Isotope	**Isotopic weight %**	**Total Pu Mass, grams**	**Isotopic Mass, grams**	**$CF_{isotope}$**	**PuE, grams**
Pu238				2.63E+02	
Pu239				1.00E+00	
Pu240				3.70E+00	
Pu241				3.30E+01	
Pu242				6.03E-02	
Am241				5.70E+01	
				PuE, total	

Equation 1, PuE (CF, isotope)

$$\mathbf{PuE} = \sum_{\mathbf{0}}^{\mathbf{n}}(\mathbf{M, isotope} \cdot \mathbf{CF, isotope})$$

M, isotope = Isotopic Mass (grams)
CF, isotope = Isotopic Conversion Factor

Equation 2, M,isotope

$$\mathbf{M, isotope} = \mathbf{M, total} \cdot \mathbf{Isotope}\ \text{weight}\ \%$$

M, total = Plutonium mass